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ABSTRACT

Research in science and mathematics education has indicated that students often use inappropriate models for solving problems because they tend to mentally represent a problem according to surface features instead of referring to scientific concepts and features. The objective of the study reported in this paper was to determine whether 34 Israeli 11th grade students who studied physics as their major (novices) and who studied and mastered both topics in mechanics (dynamics and mechanical energy) exhibited a preference for a process-based model (Newton's Laws of Motion) or a structure based model (the Law of Conservation of Energy). This study compared the novice approach with the experienced problem solvers (22 high school physics teachers--experts). The problems given were both open ended and multiple choice. The results indicate that the majority of experts preferred the structure-based model and the novices preferred the process-based model. The use of the process based model allows the solver to construct a sequence of events that are causally related to each other and lead him/her to the required solution. The structure-based model is not connected to any causal sequence of known events, requiring instead a leap from the initial to the final state. It is concluded that reasoning in terms of processes is more intuitive than reasoning in terms of states or structures. (Contains 14 references.) (PR)

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STUDENTS' PROBLEM-SOLVING IN MECHANICS: PREFERENCE OF A PROCESS BASED MODEL

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INTRODUCTION

Research in science and mathematics education has indicated that students often use inappropriate models for solving problems in these subjects (Fischbein, 1987; McCloskey, 1983). This phenomenon can be attributed to the fact that inexperienced solvers (novices) tend to mentally represent a given problem according to surface features, whereas experienced solvers (experts) refer to scientific concepts and principles (Carey, 1985; Chi, Feltovich & Glaser, 1981; Chi, Glaser & Reese, 1982; Fischbein, Tirosh, Stavy & Oster, 1990; Hardiman, Dufresne & Mestre, 1989; Larkin, 1983; Larkin & Reinhard, 1984; Stavy & Tirosh, in press). However, there are many problems in science and mathe-matics which can be represented by more than one scientific model. For example, certain problems in mechanics can be represented and solved either by Newton's Laws of Motion, or by the Law of Conservation of Energy. Both models involve formal scientific concepts and principles, but the first represents the process from the initial to the final state (process based model) while the second one represents only the initial and the final states (structure or state based model). The structure based model developed much later than the process one in the history of science and it is much more general and powerful. The use of the Law of the Conservation of Energy is usually the quickest, most certain and convenient way to tackle the solution of any problem of this kind. In mathematics, too, it is possible to relate to functions as processes or, as accepted in modern text-books of mathematics, as structures. In a study by Sphard (1991) it was found that in spite of the fact that students were taught the structure based model of functions they still perceived them in process based terms.

The objective of the present study is to find out whether physics-major high school students (novices) who studied and mastered both topics in mechanics (dynamics and mechanical energy) will exhibit a preference for one of the models (process based or structure based), and how they compare with experienced solvers - high school physics teachers. Will students, as well as teachers, use the structure based model, as expected, or will they follow the history of science and first adopt the process based model? This issue has importance both

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from a theoretical and from a practical point of view. From the theoretical aspect it is of interest to know whether process based models are more acceptable and more intuitive for the human mind than structure based models. From the practical perspective the information obtained by such a study might contribute to the improvement of science teaching in general and to the teaching of mechanics in particular.

METHOD

Subjects

The research population comprised two groups:

a) Novices - thirty-four eleventh grade students who studied physics as their major subject. All of them had finished studying a chapter on dynamics and a chapter on mechanical energy, and achieved a grade of at least 80% in each of these topics.

b) Experts - twenty-two adults who had at least a bachelor's degree in physics. Four of them were studying towards their master's degree in physics and eighteen were high-school physics teachers who were participating in an inservice course on electricity.

The Problems

Two types of problems were presented:

a) open-ended computational problems

b) multiple-choice problems

a) Open-ended computational problems - five problems were presented, each of which could be solved by using either Newton's Laws of Motion (process approach) or the Law of Conservation of Energy (structure based model). In all of them the use of the structural approach was simpler and shorter. Subjects were asked to solve the problems in the shortest way they could.

b) Multiple-choice problems - two problems were presented, each followed by (four or six) possible answers related to both the process based and the structure based models (in the first problem three out of the four possible answers were correct, two relating to the structural and one to the process approach; in the second problem two out of the six possible answers were correct, one relating to the structural and the other to the process based model).

Procedure

The problems were presented to all subjects during two class periods (90 minutes). In order not to rouse students' attention to the two possible models for solution, the open-ended problems were first administered and only then the multiple-choice problems.

A novice or an expert is considered as consistent in preferring a model, if he/she preferred one model in solving at least four out of the five problems in the open-ended section, and selected all the correct answers for the multiple- choice problems that were associated with the same model.

RESULTS

Responses to the open-ended problems

Table 1 presents the average score (in percents) of novice students and of expert teachers in the open-ended computational problems.

As can be seen from Table 1, all expert teachers and the majority of novice students succeeded in solving all problems. However, while the majority of experts preferred the structure based model, and only two of them solved all problems by means of the process approach model, the majority of novices preferred the process based one. These two teachers had been teaching the chapter on dynamics at the time of the research and were probably influenced by it. One of the open-ended problems was much more difficult to solve by means of the process based model than were the others. And indeed, fourteen out of the thirty-four novices failed to do so. Four of them succeeded in solving this problem by shifting to the structure based model, after they had realized that they could not solve it by means of the process based model.

Table 1: Average scores of novice students and of expert teachers for the open-ended problems (in percents)

Subjects	Average Score		
	general	in process based solutions*	in structure based solutions*
Novice students N = 34	85.0	78.6	6.4
Expert teachers N = 22	100.0	25.6	74.4

* calculated from all possible process based solutions
** calculated from all possible structure based solutions

Table 2 presents the average score of novice students and of expert teachers in the multiple-choice problems. As can be seen from Table 2, the majority of the experts succeeded in choosing all the correct answers (process based as well as structure based) to both problems without showing a preference for a particular model. The average score of the novices was 58%. They chose 77.9% of the correct process based answers and 38.1% of the correct structure based ones.

Table 2: Average scores of novice students and of expert teachers in the multiple-choice problems (in percents)

Subjects	Average Score		
	general	in process based solutions*	in structure based solutions*
Novice students N = 34	58.0	77.9	38.1
Expert teachers N = 22	90.0	90.0	90.0

* calculated from all possible correct process based solutions
** calculated from all possible correct structure based solutions

Consistency in choice of an approach

About half of the novices consistently preferred the process based model in solving the open-ended problems. They also selected all the correct process based answers in the multiple-choice problems, and only 18% of them also selected the structure based answers. In contrast, about half of the experts consistently used the structure based model in the open-ended problems, and all of them selected all the correct answers in the multiple-choice ones (structure based as well as process based). The two experts who preferred the (process approach) in the open-ended were those who had been teaching the chapters on dynamics, yet they selected all the correct answers in the multiple-choice problems.

DISCUSSION

The main objective of the present study was to test the hypothesis that the process based model is more accessible or more intuitive than the structure based model. In order to test this hypothesis, novice students who had studied and mastered the topics of dynamics and

mechanical energy, and expert physics teachers were presented with open-ended computational problems in mechanics which could be solved either by using the process based model (Newton's Laws of Motion) or by using the structure based model (The Law of Conservation of Energy). As the structure based model is more general and powerful and its use is simpler and shorter, it was expected that all the expert physics teachers would prefer its use. If both models are equally acceptable or equally intuitive then it can also be expected that novices who studied both models would prefer the use of the "better" structure based one. If, however, the process approach is more acceptable and/or more intuitive, it should be expected that students who are novices with regard to both models, would prefer its use.

We found that the majority of the experts preferred, as expected, the use of the structure based model. However, most novice students clearly preferred the use of the process based model. As mentioned above, both models involve formal scientific concepts and principles, but while the process based model relates to the *process*, the structure based one relates to the initial and final *states* only. The use of the process based model enables the solver to construct a sequence of events which are causally related to each other and lead him/her to the required solution. On the other hand, the structure based model is not connected to any causal sequence of known events (Warren, 1983), requiring instead a leap from the initial to the final state. It seems that reasoning in terms of processes is more intuitive than reasoning in terms of states or structure.

It could be argued that novices and experts approach the core concepts differently and that experts possess superordinate concepts that the novices lack (Chi, Glaser & Reese, 1982). However, our results from the multiple-choice problems indicate that the novice students whose average score in the structure based model answers to the open-ended problems was only 6.4%, scored about 40% in the structure based model answers to the multiple-choice problems (which suggested both models of solution). Moreover, about one-third of the novice students who exhibited a very strong preference for the process based model in the open-ended computational problems (solving at least four out of the five problems by recourse to the process based model) nevertheless also succeed to select structure based model answers when solving the multiple-choice problems. These results, in addition to the fact that all of these students were physics majors, were instructed in dynamics as well as in mechanical energy, and scored very high in both topics, might indicate that the novice students apparently did not lack the superordinate concept of energy, but rather that they preferred the use of the process based model when presented with the open-ended problems.

It should be mentioned that some of the novice students, in spite of having been instructed and successful in both dynamics and mechanical energy, did not choose any structure based model answers in the multiple-choice problems. It might be that their

preference for the process based model was so strong that they did not consider the structural approach as at all relevant to these types of problems.

It could also be argued that the concept of energy is more formal, more abstract or more difficult than concepts related to the process based model (force, acceleration, etc.). Both types of concepts were found to be difficult for students to grasp (e.g., Duit, 1981; McCloskey, 1983). It might very well be that if the concept of energy is indeed more difficult this is because it relates to the initial and final states only and not to the process.

It is noteworthy that students' preference for process based models was also observed in mathematics, with regard to the concept of function (Sphard, 1991) and with regard to the concept of infinity (Fischbein, Tirosh & Hess, 1979). In all these cases, including the present one, the process based model preceded the structure based one in the history of mathematics and science, and in all of them the structure based model is more general and more powerful.

EDUCATIONAL IMPLICATIONS

When physics teachers deal with the law of conservation of energy they should be aware of students' difficulties in grasping "structure based" models. They should pay special attention to the fact that much training is needed in order to make the student think about physical situations in terms of "states" or "structures".

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